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IMPEDANCE SOURCE INVERTER TOPOLOGIES FOR PHOTOVOLTAIC APPLICATIONS – A REVIEW

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ABSTRACT

The impedance source inverters can step up the voltage and hence, they are greatly preferred for photovoltaic applications. There are many impedance and quasi impedance network topologies available. The key factor in selection of topology is the amount of voltage gain obtained along with the reduced number components. This paper compares some of the impedance and quasi - impedance source inverter (qZSI) topologies for photovoltaic applications namely, switched coupled inductor qZSI, switched ZSI, enhanced-boost quasi ZSI with continuous and discontinuous source current topologies, enhanced -boost active qZSI, switched-boost ZSI and high gain switched boost inverter. The parameters taken for comparison are voltage gain, boost factor, voltage, and current stresses on the components etc. Based on the comparison, the high gain switched boost ZSI is found to have high voltage gain along with reduced voltage and current stress. The review will be useful for researchers working in impedance source inverter network.

Keywords: Z source inverters, quasi - Z source inverters, voltage gain, photovoltaic applications.

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1. INTRODUNCTION

The need and utility of renewable energy sources have increased tremendously in recent years. The light energy obtained from sun is converted into electrical energy by the means of photovoltaic cells. The electrical energy thus obtained is of direct current and hence for applications requiring alternating current supply, the direct current obtained from the

photovoltaic cells needs to be converted into alternating current by means of inverter. Among the different types of inverter topologies available, the ZSI topologies are considered in the paper. The categorization of ZSI presented in this paper is depicted in Figure 1.

The load voltage is always lesser than the source voltage in conventional voltage source inverters. But for photovoltaic applications the input voltage is required to be boosted. Thus, while using the conventional VSI, it requires an additional DC – DC converter interface. This additional converter increases the losses as well as cost of the system. Therefore, the ZSI are preferred[1]. In the ZSI, the inverter has inherent boosting capabilities and thus, the need of the intermediate stage of voltage conversion is eliminated. The main limitation of impedance source inverter are discontinuous input current which leads to high input current ripple, large inrush current and high voltage stress across capacitors. With the help of qZSI, these constraints are suppressed [2][3]. This not only has the feature of boosting the input voltage but also its source current is continuous which results in the reduction of input current ripples along with lower voltage stress on components and dc source and H - bridge is connected to a common ground.

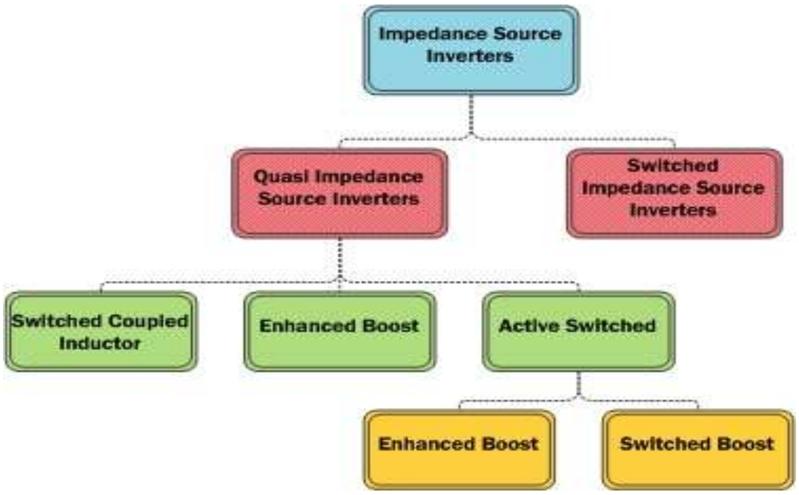


Figure 1 Catagorization of ZSI

But the trade-off that lies between the modulation index(M) and the shoot through duty cycle(D), restricts the voltage gain (G) of both the topologies. The relationship of M and D is given as $M \leq 1\text{-}D$[4] for sinusoidal pulse width modulation (SPWM). Therefore, increased shoot through ratio results in decreased modulation index. Having a lower M value, reduces the quality of output waveform. Hence, to improve the voltage gain of the inverter, modified impedance and quasi-impedance source inverters are used. One method of improving the gain value is to use switched capacitors or active switched capacitors and switched inductors (SL)/ switched coupled inductors (SCL) instead of traditional inductors in the network[4] – [21]. This has improved voltage gain yet due to the leakage inductances in the coupled inductor the output voltage has spikes superimposed on it. Without using transformers or coupled inductors the enhanced boost qZSI topologies provide higher voltage gain values using additional passive components (EB - qZSI) [22] – [26]. However, addition of a greater number of passive components to the network increases the losses associated with them and hence the efficiency is reduced. The reduction in number of passive components is achieved by replacing some of them with an active switch i.e., active switched networks [27] – [34]. In active switched Z source inverter (SZSI), higher voltage gain values are obtained with smaller duty cycle ratio which in turn gives space to operate the H- bridge inverters with high modulation index value. In order to further enhance the boosting capabilities of the inverter, switched boost topologies were introduced [35]-[39]. By incorporating better pulse width modulation, better performance

of the inverter can be achieved [40]-[43]. Some of these switched inductor, enhanced boost and active switched and switched boost topologies are compared and presented in this paper.

2. STUDY OF IMPEDANCE SOURCE INVERTERS

2.1 Impedance Source Inverters (ZSI)

The circuit topology of conventional ZSI [1] is given in Figure 2. It consists of a combination a pair of capacitors, a pair of inductors along with the conventional H – bridge inverter. The addition of the impedance network enables a shoot through operation of the inverter where switches belonging to the same leg conducts simultaneously and is responsible for the boosting of input voltage. But the inverter input current is discontinuous causing high input current ripple.

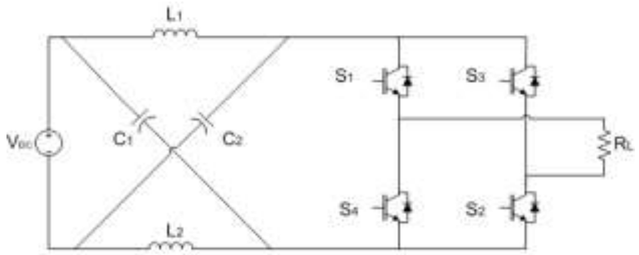


Figure 2 Topology of the ZSI

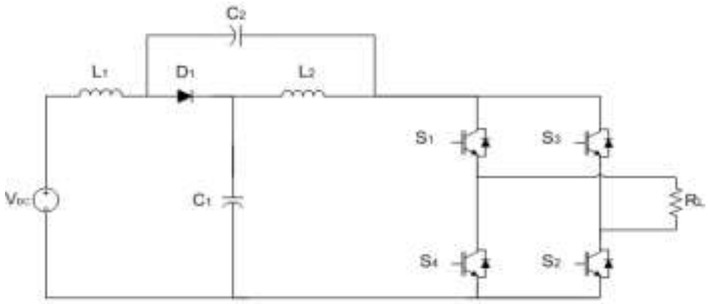


Figure 3 Topology of the qZSI inverter

2.2 Quasi Impedance Source Inverters(qZSI)

The quasi - impedance source inverter [2] has a diode in addition to the passive components of the impedance source inverter. The operation of the qZSI is same as ZSI but has a continuous source current. Hence, the current ripple of the source is minimised significantly. Figure 3 depicts the network topology of qZSI.

2.3 Switched Coupled Inductor Based Quasi- Impedance - Source Inverter (SCL-qZSI)

This is a modified quasi- Z- source inverter [9] consisting of three capacitors, three diodes and an inductor as well as a coupled inductor in place of traditional inductor as shown in Figure 4. The operation of SCL – qZSI is similar to that of qZSI but has an ability to produce higher voltage gain. There exist two operating modes. They are shoot through and non- shoot through mode. Devices of the same phase leg are simultaneously turned ON during the shoot through mode and the diodes D_2 and D_3 conducts while diode D_1 is in OFF state. The capacitor C_1 charges the winding N_1 and N_2 parallelly while capacitor C_3 gets charged through N_3 from C_1.

This increases the inverter boost factor. In the case of the non- shoot through mode, the diode D_1 is in conducting state and D_2 and D_3 do not conduct. When the windings N_1, N_2, N_3 along with C_3 connected in series supply the H – bridge, the capacitors C_1 and C_2 gets charged. Thus, with a lower shoot through duty ratio for the same input and output voltage rating can be achieved, leading to the reduction of the voltage stress on the components. It has lower inductor current ripples in the source and better output voltage quality. But, one of the major limitations is that the leakage inductance is present because of the usage of coupled inductor, thereby having spikes superimposed on the output dc link voltage, thus reducing the quality of the waveform.

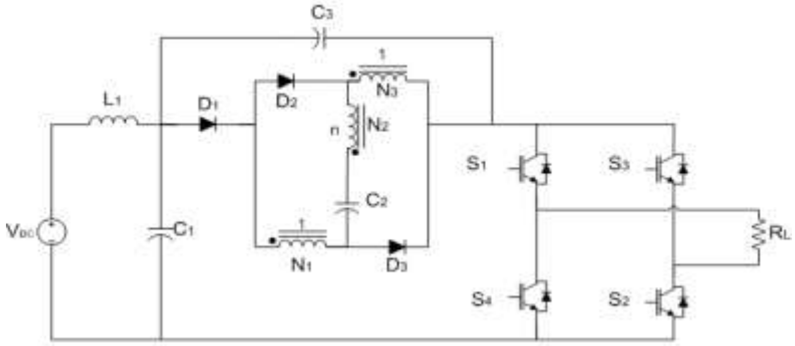
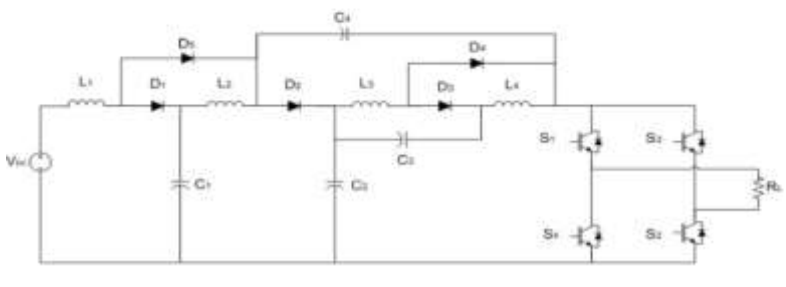


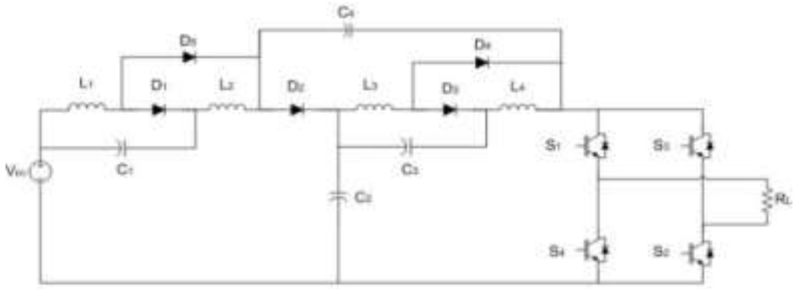
Figure 4 Circuit topology of the SCL-qZSI inverter

2.4 Enhanced Boost Quasi- Impedance Source Inverter (EB - qZSI)

The EB – qZSI consists of a combination of a pair of switched impedance network[13]. The number of components is the same in both the configurations but the connection of polarity of capacitor C_1 determines whether it operates with continuous source current(cc) or discontinuous source current(dc). EB – qZSI also has both shoot through and non - shoot through modes of operations. During the shoot through mode of operation along with the conduction of same phase leg devices, the diodes D_4 and D_5 conducts while the diodes D_1, D_2 and D_3 remain in OFF state and the inductors get charged by capacitors. In the non- shoot through mode, the diodes D_1, D_2 and D_3 starts conducting and, the diodes D_4, D_5 gets turned OFF. In this mode, the input supply charges the capacitors via inductors and the energy gets transferred to the H- bridge from in the inductor. Thus, with a small shoot through ratio the output voltage of the inverter is boosted with a high voltage gain value. This implies that the H - bridge can be operated at a higher modulation index providing better quality output voltage with reduced total harmonic distortion. Apart from high voltage gain, it has a continuous source current, suppressed inrush current and reduced the stress across the capacitor. But as the passive components used is significantly high in number, the efficiency of the inverter is low at high power. Thus, it is not suitable for high power applications. The topology of EB- qZSIs configurations for (a) cc and (b) dc are depicted in Figure. 5.



(a)



(b)

Figure 5 EB- qZSIs configurations for (a) cc and (b) dc

2.5 Enhanced Boost Active Quasi – Impedance Source Inverter (EB - AqZSI)

In EB – AqZSI,[14] the number of components of EB – qZSI is reduced by replacing a inductor capacitor pair with an active switch and thus it has a switch, a pair of capacitor, a pair of inductor and four diodes as given by Fig. 6. Both EB – AqZSI and EB – qZSI has similar operation modes. But EB – AqZSI has the same voltage gain with a reduced component count.

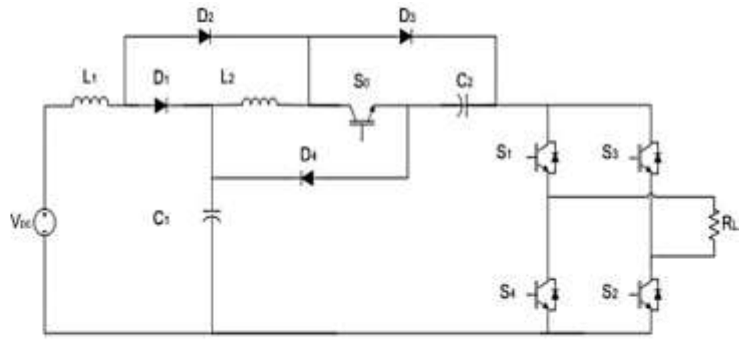


Figure 6 Topology of EB – AqZSI

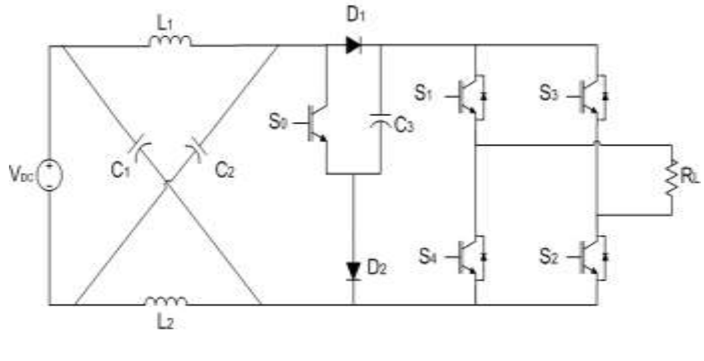


Figure 7 Topology of the SZSI

2.6 Switched Impedance Source Inverter (SZSI)

The SZSI [17] is a modified high boost ZSI with reduced active and passive components. Figure 7 gives the network topology of SZSI. It has one switch, two inductors, three capacitors and three diodes. It has three modes of operation i.e., two continuous current modes and one discontinuous current mode. Each mode has different states of operation. The two cases of operation in continuous current mode has two and three states of operation while in discontinuous current mode there exists four states of operation. One of the main advantages of

this network is with a small value of D, high G value can be achieved but the source and load doesn't share common ground.

2.7 Switched Boost Quasi – Impedance Source Inverter (SB – qZSI)

In SB – qZSI, the addition of an active switch enhances the voltage gain [18]. It consists of a switch and, a pair of capacitors, inductors and diodes and, the network topology is shown in Figure 8. This inverter operates in two modes: shoot through and non – shoot through. In the shoot through mode the switch S_0 is in ON state along with the switches of the same phase leg. It has higher efficiency and lower capacitor voltage stress and current stress on switch in comparison with conventional ZSI.

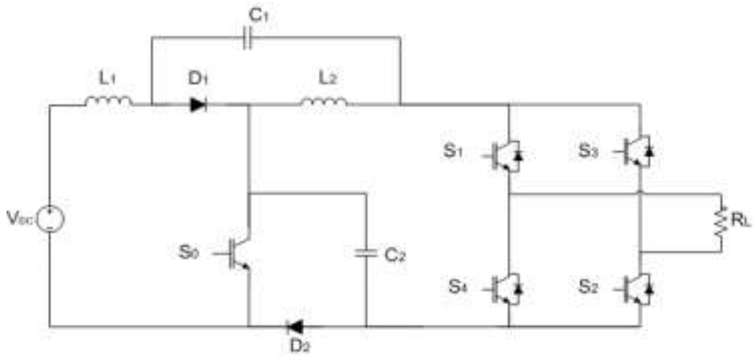


Figure 8 Topology of SB- qZSI having

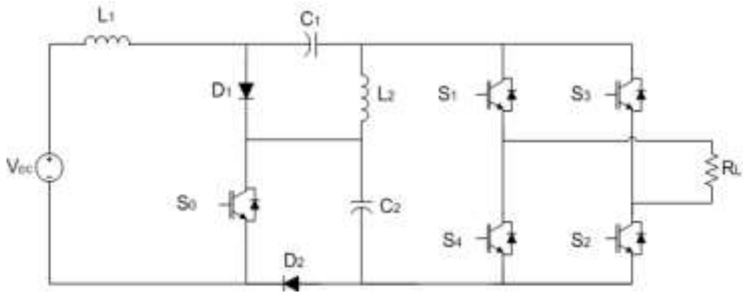


Figure 9 Topology of HG-qSBI continuous input current (cc)

2.8 High Voltage Gain Quasi – Switched Boost Inverter (HG – qSBI)

It consists of same number of components as in the case of SB – qZSI but has a higher G value and also, lower capacitor voltage stress. The topology of HG – qSBI [19] is shown in Figure 9. It has three operation modes: one shoot through (ST) mode and two non – shoot through(NST) modes. In the ST mode only the H- bridge switches are conducting while the switch S_0 remains in OFF condition with reverse biased diode D_1 and forward biased diode D_2. The charging and discharging of inductors and capacitors take place during this mode respectively. In the first NST mode, the same phase leg H – bridge switches are turned ON separately and S_0 is conducting. This mode has forward biased D_1 and reverse biased D_2 with capacitor C_2 and L_1 charging and, capacitor C_1 and L_2 discharging. In the second NST mode, S_0 is in OFF state and both the diode D_1 and D_2 are conducting with L_1 and L_2 discharging while C_1 and C_2 are charging. For a three – phase system, with an improved PWM technique, high voltage gain is achieved for a small D value[20][21].

3. COMPARISON OF VARIOUS TOPOLOGIES

3.1 Number of Components

The reduction in number of components used is a key factor in determining the performance of the inverter. The greater the number of components the greater are the losses associated with them. This leads to poor performance of the inverter. The comparison of various topologies depending on the total number of components used is shown in Figure 10. From the Figure 10. It is evident that both the topologies SB – qZSI and HG – qZSI uses least number of components. Though both of them have similar number of components. They differ in their performance.

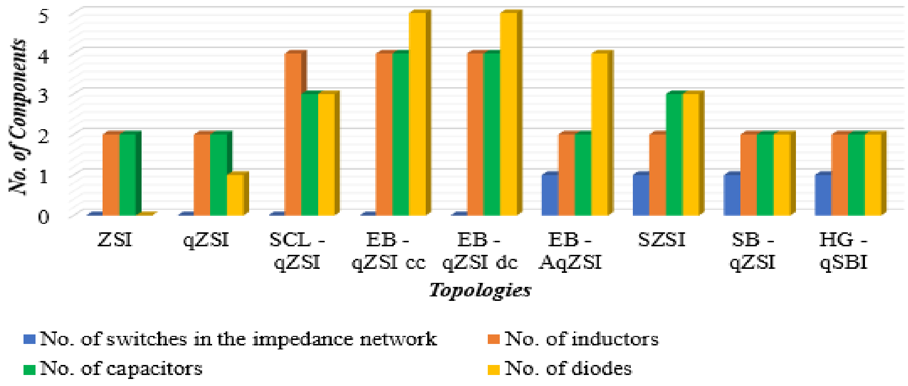


Figure 10 Comparison of different topologies based on number of components used

3.2 Voltage Gain

In comparison with the topologies presented here from Figure 11, EB – qZSI, EB – AqZSI and HG - SBI has the highest voltage gain with high modulation index. Having a higher M value, improves the quality of output voltage of the inverter. Also, in comparison with EB – qZSI and EB – AqZSI, HB – SBI uses very less number of components.

3.3 Boost Factor

Figure 12. shows the comparison of boost factor of the various topologies corresponding to the change in duty ratio. EB – qZSI, EB – AqZSI and HG - SBI has the highest G value with small value of D. This effectively reduces the voltage and current stress on the passive components. With smaller duty cycle, the modulation index can be increased to achieve better performance of the inverter.

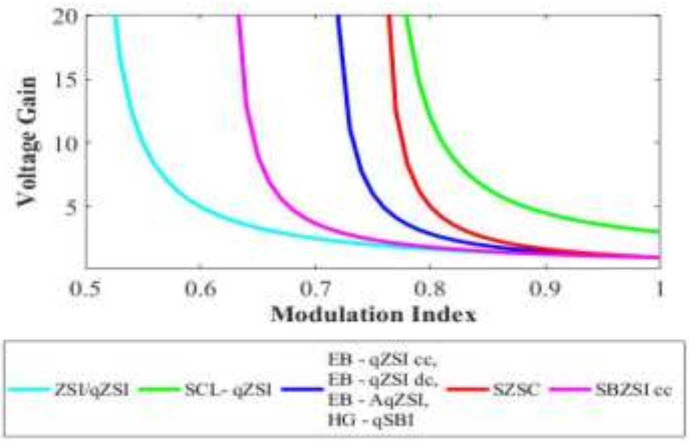


Figure 11 Voltage Gain Vs Modulation Index

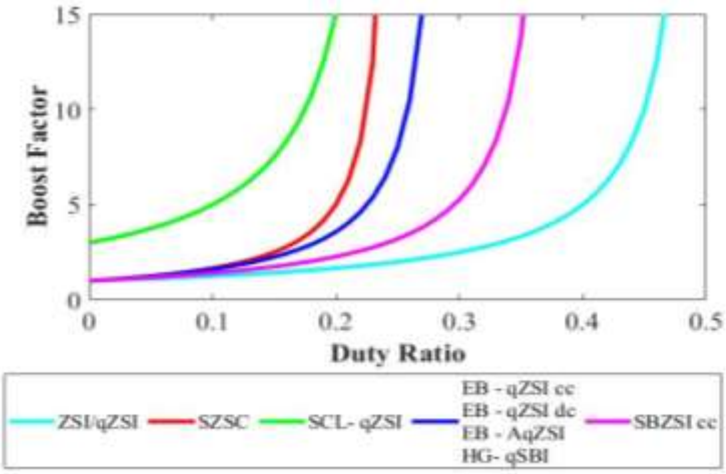


Figure 12 Boost Factor Vs Duty cycle

Table 1 Comparison of Various Impedance and Quasi- Impedance Network Topologies – Based on No. of Components Used, Voltage Gain, Boost Factor

Topology	S	L	C	D	Voltage gain	Boost Factor
ZSI	0	2	2	0	$\frac{1}{2M-1}$	$\frac{1}{1-2D}$
qZSI	0	2	2	1	$\frac{1}{2M-1}$	$\frac{1}{1-2D}$
SCL- qZSI	0	4	3	3	$\frac{3M}{4M-3}$	$\frac{3}{1-4D}$
EB- qZSI cc	0	4	4	5	$\frac{M}{2M^2-1}$	$\frac{1}{1-4D+2D^2}$
EB- qZSI dc	0	4	4	5	$\frac{M}{2M^2-1}$	$\frac{1}{1-4D+2D^2}$
EB - AqZSI	1	2	2	4	$\frac{M}{2M^2-1}$	$\frac{1}{1-4D+2D^2}$
SZSC	1	2	3	3	$\frac{1}{4M-3}$	$\frac{1}{1-4D}$
SBZSI cc	1	2	2	2	$\frac{M}{M^2+M-1}$	$\frac{1}{1-3D+D^2}$
HG- qSBI	1	2	2	2	$\frac{M}{2M^2-1}$	$\frac{1}{1-4D+2D^2}$

3.4 Voltage and Current Stress

The stress in the passive and active components of the inverter leads to increased losses in the inverter. Thus, minimisation of stress on the component increases the overall system efficiency.

The comparison of stress on the passive and active components of the inverter is shown in Table 2. Also, increased stress on the components, increase the rating of the components thereby increasing the cost and size of the inverter. With the reduction in stress, the size and cost of the inverter are reduced considerably leading to better power density of the inverter.

From Table 2, HG – SBI has lower stress on the passive components both in terms of voltage and current. However, the current stress across the active switch is more when compared with SB – ZSI.

Figure 13. shows the key features of impedance and quasi- impedance source inverters. The important features observed are high voltage gain, reduced duty cycle, reduced voltage and current stress, reduced input current ripple, reduced no. of components.

Table 2 Current and Voltage Stress Comparison of Various Impedance and Quasi- Impedance Network Topologies

Topology	**Current Stress in Inductor**	**Voltage Stress across capacitor**	**Voltage stress across the switch**	**Voltage stress across diode**
ZSI	$L_1=L_2$:$\frac{1-D}{1-2D}$	$C_1=C_2$:$\frac{1-D}{1-2D}$	NA	NA
qZSI	L_1: $\frac{(B+1)}{2}$; L_2: $\frac{(B+1)}{2}$	C_1: $\frac{(B+1)}{2}$; C_2: $\frac{(B+1)}{2}$	NA	D: B
SCL- qZSI	L_1: $\frac{3(1-D)}{1-4D}$; $N_{1,2}$:$\frac{S_D(1+D-2D^2)}{1-4D}$ N_3:$\frac{-2(1-D)^2}{1-4D}$; $N_{1,2,3}$: $\frac{\overline{S_D}(1-D)}{1-4D}$	C_1: $\frac{1-D}{3}$; C_2:$\frac{2+D}{3}$; C_3:$\frac{2(1+D)}{3}$	NA	D: $\frac{3}{1-4D}$; $D_{1,2}$: $\frac{2}{1-4D}$
EB- qZSI cc	$L_1=L_2$: $\frac{1-D}{1-4D+2D^2}$; $L_3=L_4$: $\frac{(1-D)^2}{1-4D+2D^2}$	C_1:$\frac{(1-D)^2}{1-4D+2D^2}$; C_2:$\frac{D-D^2}{1-4D+2D^2}$ C_3:$\frac{1-3D+D^2}{1-4D+2D^2}$; C_4:$\frac{2D-D^2}{1-4D+2D^2}$	NA	$D_1= D_2$:$\frac{1-D}{1-4D+2D^2}$ $D_3=D_4=D_5=D_6$: $\frac{D}{1-4D+2D^2}$
EB- qZSI dc	$L_1=L_2$: $\frac{1-D}{1-4D+2D^2}$ $L_3=L_4$: $\frac{(1-D)^2}{1-4D+2D^2}$	$C_1=$ $\frac{(1-D)^2}{1-4D+2D^2}$; $C_2=C_3$: $\frac{D-D^2}{1-4D+2D^2}$ C_4: $\frac{2D-D^2}{1-4D+2D^2}$	NA	$D_1= D_2$: $\frac{1-D}{1-4D+2D^2}$ $D_3=D_6$: $\frac{D(1+D)}{1-4D+2D^2}$ $D_4=D_5$:$\frac{D}{1-4D+2D^2}$
EB - AqZSI	$L_1=L_2$: $\frac{1-D}{1-4D+2D^2}$; $L_3=L_4$: $\frac{(1-D)^2}{1-4D+2D^2}$	C_1: $\frac{1}{1-4D+2D^2}V_{DC}$ C_2:$\frac{(1-2D)}{1-4D+2D^2}V_{DC}$	S_0:$\frac{1}{1-4D+2D^2}V_{DC}$	$D_1=D_2$:$\frac{1}{1-4D+2D^2}V_{DC}$ $D_3=$ $\frac{2(1-D}{1-4D+2D^2}V_{DC}$ D_4: $\frac{2D}{1-4D+2D^2}V_{DC}$
SZSI	L_1: $\frac{1}{1-4D}$; L_2: $\frac{1}{1-4D}$	$C_1=C_2$: $\frac{1-2D}{1-4D}$; C_3: $\frac{1}{1-4D}$	S_0: $\frac{1}{1-4D}$	D_1:$\frac{2}{1-4D}$; $D_2=D_3$:$\frac{1}{1-4D}$
SBZSI cc	L_1: $\frac{1-D}{1-3D+D^2}$; L_2: $\frac{2-2D+D^2}{1-3D+D^2}$	C_1: $\frac{D}{1-3D+D^2}$; C_2: $\frac{1-D}{1-3D+D^2}$	S_0:$\frac{1-D}{1-3D+D^2}$	D_1:$\frac{-1}{1-3D+D^2}$; D_2:$\frac{-(1-D)}{1-3D+D^2}$
HG- qSBI	L_1: $(1-D)B$ L_2:$(1-D)(1-2D)B$	$C_1=C_3$:$(1-D)B$ C_2: DB	S_0:$(1-D)B$	D_1:B ; D_2: $(1-D)B$

Figure 13 Features of impedance and quasi- impedance source inverters.

4. CONCLUSION

This paper summarizes the features of all the topologies discussed for photovoltaic applications. Depending on the number of components (both active and passive) the HG – SBI and SBZSI are considered to have lowest no. of components. EB – qZSI and HG – SBI has the highest value of G and the boost factor. The voltage and current stress across the components are found to be lower in SB – ZSI and HG – SBI. qZSI, EB- qZSI cc, SB – ZSI and HG – SBI has continuous source current and the input and output has a common ground. Therefore, the HG – SBI considered has the high value of voltage gain along with the reduced number of components with reduced input current ripple, suppressed inrush current and better efficiency in comparison with SZSC, SCL- qZSI, EB- qZSI cc, EB- qZSI dc, EB - qZSI and SB – ZSI. By improving the PWM techniques used for HB – SBI, a very high voltage gain with much smaller duty cycle can be obtained thereby making them suitable for photovoltaic applications.

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